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OPEN SLOPE STABILITY OF LATERITE NICKEL ORE IN MOROWALI UTARA

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ABSTRACT

Unstable slopes are very dangerous for mining activities because if this phenomenon occurs it will have an impact on the mining activities; therefore, a slope stability analysis is needed because slope stability is a vital factor in the planning and operation of open pit mines. The purpose of this study was to analyze the characteristics of nickel, determine the factor of safety value and slope deformation, and determine the design of safe slope geometry in an open pit mine in Morowali Regency. The method used in this research is survey research by taking samples to be analyzed using the Bishop method with the Geostudio application, and the deformation of the data is analyzed using the Element method with the Plaxis application. The results of the analysis show that the Safety Factor (SF) on Slope 2 tends to be unstable when there is no load, with a deformation value of 0.945 cm, even after being loaded with heavy equipment and an earthquake, the stability value on the slope decreases. While Slope 1 and Slope 3 are still in a stable condition when loaded with heavy equipment when given additional earthquake loads, the SF on both slopes becomes unstable.

Keywords: Stability, slope, mine, nickel.

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1. INTRODUCTION

Central Sulawesi is a nickel ore-producing region in Indonesia, one of which is placed in North Morowali Regency. PT. Trinusa Dharma Utama is engaged in the mining of nickel metal mining commodities and is located in Lambolo Hamlet, Ganda-Ganda Village, Petasia District, North Morowali Regency, Central Sulawesi Province. The mining system implemented by the company is open pit mining, where to obtain ore or nickel resources it is necessary to strip the overburden first, followed by forming the geometry so that slopes with different slopes and heights are formed. The difference in slope and height will cause a new stress distribution because it disrupts the voltage distribution on the existing natural slope, so this sometimes causes work accidents due to landslides on the slopes in the mine area. One of the consequences of the new voltage distribution is in the form of collapse/slide as one of the natural properties of the slope to seek a new equilibrium by reducing the load it bears.

Landslide is one of the most frequent occurrences in several places at mining sites due to a decrease in the shear strength of a soil mass. In other words, the shear strength of a soil mass is unable to carry the existing workload. Unstable slopes are very dangerous for mining activities because at any time this phenomenon will occur and have an impact on these mining activities, slope stability is a vital factor in the planning and operation of open pit mines. In preparing a mine plan, apart from reserves, mining techniques, economics, and the environment, slope stability is also an important factor that must be carefully considered. Stable slope design will have a major impact on mining economics, as well as the sustainability of mine production.

The aims of this research are:

a) Analyze the characteristics of nickel in the open pit mining area in Morowali Regency.

b) Analyze the value of the slope safety factor in the open pit mine area in Morowali Regency.

c) To determine slope deformation in open pit mining areas in Morowali Regency.

2. LITERATURE REVIEW

2.1 Soil Characteristics

A. Permeability

Permeability is defined as the property of a porous material that allows the seepage of fluids in the form of water or oil to flow through the pore cavities. The pores in the soil are interconnected, which makes air flow from high to low pressure. In soils, permeability is defined as the property of the soil to allow air to flow through the pore spaces of the soil. According to Das (1995) in Soil Mechanics 1, Sixth Edition, the range of permeability values for soil types can be seen in the following table.

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Table-1. Permeability coefficient value.

No.	Type of soil	k (mm/detik)
1.	Coarse Grain	$10 – 10^3$
2.	Fine gravel, coarse grain mixed with medium sand	$10^{-2} – 10$
3.	Fine sand, loess silt	$10^{-4} – 10^{-2}$
4.	Solid silt, loamy silt	$10^{-5} – 10^{-4}$
5.	Loamy loam, loam	$10^{-8} – 10^{-5}$

Source: Hardiyatmo, (2014)

B. Elastic Modulus

The elastic modulus is a value that shows the magnitude of the soil elasticity number from the ratio between the stress that occurs to the strain. This estimated value can be determined from the type of soil as shown in the following table.

Table-2. Nilai Perkiraan Modulus Elastisitas Tanah.

No.	Type of soil	E (kN/m^2)
1.	Clay: Very soft Soft Medium Hard Sandy	300 – 3000 2000 – 4000 4500 – 9000 7000 – 20000 30000 - 42500
2.	Sand: Silt Not solid Solid	5000 – 20000 10000 – 250000 50000 - 100000
3.	Sand and gravel: Solid Not solid	80000 – 200000 50000 - 140000
No.	Type of soil	E (kN/m^2)
4.	Silt	2000 – 20000
5.	Loess	15000 – 60000
6.	Rock	140000 - 1400000

Source: Bowles (1989) in Hardiyatmo (2014)

C. Poisson Ratio

The Poisson ratio value determines the ratio of shaft compression to lateral expansion strain. This value can be determined based on the type of soil as shown in the following table.

Table-3. Relationship between type of soil with poisson ratio.

No	Type of soil	***Poisson Ratio***
1	Saturated clay	0,4 – 0,5
2	Unsaturated clay	0,1 – 0,3
3	Sandy loam	0,2 – 0,3
4	Silt	0,3 – 0,35
5	Solid Sand	0,2 – 0,4
6	Not dense sand	0,15
7	Fine sand	0,25
8	Rock	0,1 – 0,4
9	Loess	0,1 – 0,3

Source: Hardiyatmo (2014)

D. Internal Shear Angle

Internal shear strength has variable cohesion and internal shear angle. The internal shear angle together with cohesion determines the resistance of the soil due to the applied stress in the form of lateral soil pressure. This value is also obtained from the measurement of soil engineering properties with the Direct Shear Test. The relationship between the internal shear angle and the soil type is shown in the following table.

Table-4. Relationship Between Inner Shear Angle and Soil Type.

Type of soil	Inner Shear Angle (Ø)
Sandy gravel	$35^o – 40^o$
Pebbles	$35^o – 40^o$
Solid sand	$35^o – 40^o$
Loose sand	30^o
Silt clay	$25^o – 30^o$
Clay	$20^o – 25^o$

Source: Das (1995)

E. Cohesion

Cohesion is the attractive force between soil particles. Together with the internal shear angle, cohesion is a parameter of soil shear strength that determines soil resistance to deformation due to stresses affecting the soil, which is in the form of lateral movement of the soil. This deformation occurs due to a combination of critical conditions at normal and shear stresses that are not following the safety factor of the design. This value is obtained from the Direct Shear Test. The value of cohesion empirically can be determined from sondir (qc) data as follows:

Cohesion (c) = qc/20 (Source: Das, 1995)

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Conus pressure (qc) data and adhesive resistance (fs) obtained from sondir test results. These are used to determine the type of soil as shown in the following table.

Table-5. Soil Classification from Sondir Data.

Sondir Results		**Classification**
Qc	**fs**	
6,0	0,15 - 0,40	Humus, very soft clay
6,0 - 10,0	0,20	Loose silty sand, very loose sand
	0,20 - 0,60	Soft clay, soft silty clay
Sondir Results		Classification
Qc	fs	
10,0 - 30,0	0,10	Loose pebbles
	0,10 - 0,40	Loose sand
	0,40 - 0,80	Clay or silty clay
	0,80 - 2,00	The clay is slightly chewy
30 – 60	1,50	Silt sand, slightly dense sand
	1,0 - 3,0	Chewy clay or silty loam
60 - 150	1,0	Loose sandy gravel
	1,0 - 3,0	Compacted sand, silty sand, or compacted loam and silty loam
	3,0	Chewy gravelly clay
150 - 300	1,0 - 2,0	Dense sand, gravelly sand, coarse sand, very dense silty sand

Source: Das (1995)

The relationship between consistency of conus pressure and undrained cohesion is proportional where the higher the c and qc values, the harder the soil is. As seen in the following.

Table-6. The relationship between consistencies with conus pressure.

Soil Consistency	**Conus Pressure qc (kg/cm^2)**	**Undrained Cohesion (T/m^2)**
Very Soft	< 2,50	< 1,25
Soft	2,50 - 5,0	1,25 - 2,50
Medium Stiff	5,0-10,0	2,50 - 5,0
Stiff	10,0-20,0	5,0 - 10,0
Very Stiff	20,0-40,0	10,0 - 20,0
Hard	> 40,0	> 20,0

Source: Begeman (1965) in Hardiyatmo (2014)

Likewise, in Table-7 the NSPT value, qc, and φ are comparable.

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Table-7. Relationship between Density, *Relative Density*, NSPT value, qc dan φ.

Density	Relatif Density (γd)	N SPT Value	Conus Pressure qc (kg/cm^2)	Sliding Angle (φ)
Very Loose	< 0,2	< 4	< 20	< 30
Loose	0,2 – 0,4	4 – 10	20 – 40	30 – 35
Medium Dense	0,4 – 0,6	10 – 30	40,0 – 120	35 – 40
Dense	0,6 – 0,8	30 – 50	120 – 200	40 – 45
Very Dense	0,8 – 1,0	> 50	> 200	> 45

Source: Mayerhof (1965) Hardiyatmo (2014)

2.2 Slope Safety Factor

Things that need to be considered in determining the safety factor criteria are the risks faced, load conditions, and parameters used in conducting slope stability analysis. The risks faced are divided into three, namely: high, medium, and low. The task of an engineer is to examine the stability of the slope to determine the factor of safety. In general, the safety factor is explained as follows (Gazali *et al.*, 2020):

$$FK = \frac{\tau_f}{\tau_d} \quad (1)$$

Where:
FK = safety value against soil strength.
τf = the average shear strength of the soil.
τd = The average shear stress acting along the plane of the slide.

The shear strength of a field consists of two components, friction and cohesion, and can be written as:

$$\tau f = c + \sigma \tan \varphi \quad (2)$$

Where:
c = retained soil cohesion
φ = Inner Shear Angle
σ = the average normal stress on the surface of the sliding surface.
Or can be written as follows:

$$\tau d = cd + \sigma \tan \varphi d \quad (3)$$

Where cd is the cohesion and φd is the shear angle acting along the sliding plane. By substituting equation (2.8) and equation (2.9) into equation (2.7) we get a new equation, namely:

$$FK = \frac{c + \sigma \tan \varphi}{c_d + \sigma \tan \varphi_d} \quad (4)$$

Now we can find out several other parameters that affect the safety factor, namely the safety factor for cohesion, Fc, and the safety factor for shear angle, Fφ. Thus we can define Fc and Fφ as:

$$F_c = \frac{c}{c_d} \quad (5)$$

and

$$F_\varphi = \frac{\tan \varphi}{\tan \varphi_d} \quad (6)$$

When the equations (2.6), (2.7), and (2.8) are compared, it is natural that Fc becomes the same as Fφ, this value provides a safety factor for soil strength. Or, if

$$\frac{c}{c_d} = \frac{\tan \varphi}{\tan \varphi_d} \quad (7)$$

Can be written as

$$FK = Fc = F\varphi \quad (8)$$

FK equals 1 then the slope is in a state of landslide. Usually, safety figures against acceptable shear strength to plan slope stability (SKBI-2.3.06, 1987). The parameters used relate to the test results with a limit or residual values taking into account their accuracy.

2.3 Program Metode Elemen Hingga/Plaxis

In general, Plaxis 2D is software based on the finite element approach which is used to analyze various geotechnical applications such as deformation, stability, and groundwater flow. Through the Plaxis 2D software, soil can be modeled to estimate the behavior of the soil. Analysis of the effect of interaction between soil and structure can be modeled through this software. The program employs an easy-to-use graphical interface so that users can quickly create geometric models and mesh elements based on cross-sections of the conditions to be analyzed. This program consists of four sub-programs namely input, calculation, output, and curve. Analysis using the finite element method in a program requires prior modeling.

2.4 Simplified Bishop Method

One of the boundary balance methods for landslides is the Bishop method. This method describes the vertical force balance for each segment and the overall moment balance concerning the center of the circle. The layer above the landslide plane is divided into several vertical segments so that the soil/rock layer can be considered and the width of each segment does not have to be the same. The normal force at the base of each segment is determined by adding the forces in the vertical direction. This method ignores the frictional forces on the segments

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and then assumes a normal force sufficient to define the forces between the segments (Bishop in Cosner, 2019).

In this method, it is assumed that the total normal forces are/act at the center of the section base and can be determined by plotting the forces on the section vertically or normally. Equilibrium requirements apply to the pieces that make up the slope. The Bishop method assumes that the forces acting on the slices have a zero resultant in the vertical direction (Bishop in Rajagukguk and Monintja, 2014).

3. RESEARCH METHOD

This research was conducted in Block B7 PT. Trinusa Dharma Utama which is geographically located at coordinates 121°18'50” to 121°19'50”E and 1°52'50” to 0°54'50” South Latitude in Lambolo Hamlet, Ganda-Ganda Village, Petasia District, North Morowali, Central Sulawesi Province which is engaged in nickel mining activities.

Equipment and materials needed in this study include:

a) Hardware in the form of a computer
b) Software in the form of:
a. Microsoft Excel
b. Plaxis V 8.6
c. Geostudio (Slope/W)
d. Qgis 10.8
c) A direct sliding tool consisting of:
a. Handlebar pressure and load giver.
b. Slider complete with proving ring and two slide dials.
c. The split check ring with lock is located in the box.
d. Press load
e. Two pore stones
d) Extruder (tool for removing soil samples) and knife.
e) Print the ring of the test piece
f) Digital Scales
g) Ovens

Then for materials, namely soil samples in the research location.

Data processing in this study was used with two methods, namely calculating the safety factor on the slope using Geostudio (Slope/W) and deformation on the slope using Plaxis 2D V8.6.

a) Calculating the amount of slope deformation using Plaxis 2D V8.6.
b) Calculating the slope factor of safety using the Bishop method manually and computationally using Geostudio (Slope/W)

4. RESULTS AND DISCUSSIONS

4.1 Characteristics of Nickel in Open Pit Mining Areas in Morowali Regency

The nickel ore is located in the North Morowali area, to be precise, in the IUP of PT. Trinusa Dharma Utama in Ganda-Ganda Village, Petasia District, belongs to the nickel laterite and silicate (garnierite) types. Laterite deposits start from weathering ultramafic rocks (peridotite, dunite, serpentinite) which contain lots of olivines, pyroxene, magnesium silicate, and iron silicate minerals. The lateralization process in lateritic nickel deposits is defined as a leaching process of soluble minerals and silica minerals from the laterite profile in an acidic, warm, and humid environment, and forms a concentration of precipitate resulting from the enrichment of the lateralization process in the elements Fe, Cr, Al, Ni, and Co (PT. Trinusa Dharma Utama, 2022).

Surface water containing CO2 from the atmosphere and re-enriched by organic materials on the surface seeps below the soil surface to the leaching zone, where groundwater fluctuations occur. As a result of these fluctuations, CO2-rich groundwater will come into contact with the saprolite zone which still contains the original rock and dissolves unstable minerals such as olivine/serpentine and pyroxene. The elements Mg, Si, and Ni will dissolve and be carried away according to the flow of groundwater and will form new minerals in the process of re-deposition. Iron precipitates combined with oxides will accumulate close to the soil surface, while magnesium, nickel, and silica will remain in solution and move downwards as long as the supply of water entering the soil continues. This series of processes is a process of weathering and leaching (PT. Trinusa Dharma Utama, 2022).

In further weathering processes magnesium (Mg), Silica (Si), and Nickel (Ni) will remain in the solution as long as the water is still acidic. However, if neutralized due to reactions with rocks and soil, these substances will tend to precipitate as hydro silicate minerals (Ni-magnesium hydro silicate) called garnierite minerals [(Ni, Mg) 6Si4O10(OH)8] or Ni carrier minerals (PT)., Trinusa Dharma Utama, 2022). There is a water supply and a channel for water to fall, in this case in the form of joints or fractures in the rock, so the Ni carried by the water will drop down, gradually accumulating in the zone when the water can't go down anymore and can't penetrate the bedrock (bedrock). Bonds of Ni associated with Mg, SiO, and H will form the mineral garnierite. If this process continues, what will happen is a supergene enrichment process. This supergene enrichment zone is formed in the saprolite zone (PT. Trinusa Dharma Utama, 2022). Then the author performs a correlation between geochemical and physical data based on drill point data.

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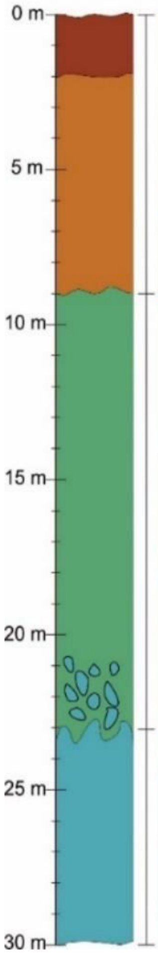

	Persentase Unsur Kimia (%)				
	Ni	Fe	MgO	SiO2	Al2O3
Limonit	0.160-1.530	14.550-51.164	0.300-12.240	0.030-47.320	1.870-11.920
Saprolit	0.320-2.081	5.080-55.310	0.180-26.440	0.010-58.370	0.390-10.960
Bedrock	0.200-0.660	4.390-7.410	0.210-33.380	0.030-58.750	0.750-7.730

Figure-1. Correlation of the percentage of chemical elements with each zone in the laterite profile.

Based on the correlation results, it can be seen that the content of Fe and Al2O3 elements is high in the limonite zone; the value is higher when approaching the surface which is characterized by a brownish-red color and gets darker towards the top. The minerals contained are dominated by oxide minerals, namely manganese, hematite, and goethite, and also found a little silica. This could be due to the oxidation process in the elements Fe and Al2O3 besides that these elements also have non-mobile properties. From the surface, the lower the depth, the lower the value of Fe and Al2O3 while the Ni, SiO2, and MgO increase. In the saprolite layer, the tendency for Ni is greater because, in this layer, the Ni element is enriched. The enrichment of Ni in this layer is formed from an alteration process, while the more limonite the element decomposes. The saprolite layers are characterized by minerals such as garnierite, goethite, serpentinite, and silica. At a depth of 23 meters, at the boundary between the saprolite and bedrock zones, silica boxwork was found with its chemical properties characterized by increased MgO and SiO2. In the bedrock layer, SiO2 and MgO dominate, which are the constituent elements of the rock layer. Bedrock layers are characterized by minerals such as olivine, pyroxene, orthopyroxene, serpentinite, chromite, and chlorite.

Furthermore, regarding the distribution of laterite nickel zone/layer thickness in the study area, the researchers also visualized the distribution of lateritic nickel deposits in the form of a 2-dimensional distribution map of nickel laterite, as the researchers presented in the following figure.

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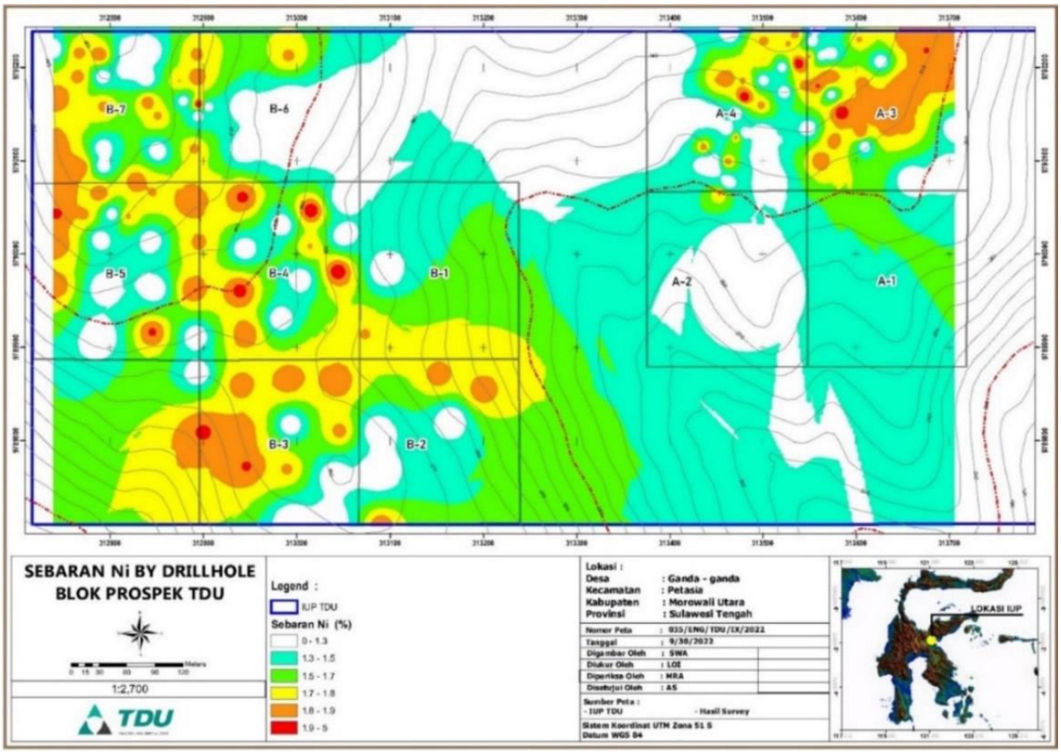

Figure-2. Map of the distribution of nickel laterite based on the percentage of NI content. (Source: PT. Trinusa Dharma Utama, 2022)

The distribution of nickel laterite zones in the study area, especially in the limonite and saprolite zones, shows that they have a north-south orientation on the western ridge and a west-east orientation to the southeast in the central to eastern parts of the study area. In this area, it is also seen that the enrichment process of the Ni element occurs optimally so that it can produce relatively high levels when compared to other morphologies.

4.2 Slope Safety Factor in Open Pit Mining Area in Morowali Regency

Before analyzing the stability of the slopes, the researchers first determined several parameters, including loading, soil parameters, and slope geometry.

A. Loading

a) Earthquake Load Data

Sulawesi Island, especially in the North Worowali region, Central Sulawesi, is an area that is not immune from the threat of earthquakes. Thus, the earthquake load factor will be included in the analysis. On the earthquake zoning map obtained from the Indonesian Earthquake Source and Hazard Map Update Team (2017), the earthquake acceleration in this region is 0.4 - 0.5 g. However, the earthquake load used is the earthquake load with the largest value of 0.5 g. The time interval of the earthquake which is included in the praxis is taken for 5 seconds assuming it has passed the peak acceleration. The following is a picture of the Indonesian earthquake zoning map.

b) Heavy equipment load

Each bench at the mine site carries a load in the form of a Komatsu PC 200 excavator weighing up to 20 tons (196.13 KN). The equivalent load is carried out to change the concentrated load of 196.13 KN into an evenly distributed load. L is the width of the lane or road where the heavy equipment is actively carrying out excavations that are up to 7 m wide:

$$\frac{1}{4}PL = \frac{1}{8}qL^2$$

$$\frac{1}{4} \text{ x } 196{,}13 \text{ x } 7 = \frac{1}{8} \text{x } q \text{ x } 7^2$$

q = 56, 03 KN/m^2

So the total load that is evenly distributed is 56.03 KN/m2.

A. Soil Parameters

The values of the parameters used in the analysis with the help of the Geoslope and Plaxis programs are based on the following data:

- Input Slope/W

The input required for Slope/W in the analysis of slope stability with the Mohr-Coloumb shear strength model is:

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Table-8. Soil parameters of each slope.

Depth (m)	Layer Type	Slope Land Parameters 1	Slope Land Parameters 2	Slope Land Parameters 3
0-2	Top Soil	**Cohesion (τ) = 20.839 Kn/m³**	**Cohesion (c) = 25.056 Kn/m³**	**Cohesion (c) = 16.436 Kn/m³**
		sliding angle(φ) = 24.570°	sliding angle(φ) = 21.390°	sliding angle(φ) = 18.583°
		Soil Fill Weight= 15.278 Kn/m³	Soil Fill Weight= 12.448 Kn/m³	Soil Fill Weight= 11.818 Kn/m³
2-9	Limonite	Cohesion (τ) = 25.850 Kn/m³	Cohesion (c) = 12.925 Kn/m³	Cohesion (c) = 27.665 Kn/m³
		sliding angle(φ) = 21.306°	sliding angle(φ) = 22.626°	sliding angle(φ) = 21.882°
		Soil Fill Weight= 13.242 Kn/m³	Soil Fill Weight= 15.279 Kn/m³	Soil Fill Weight= 12.811 Kn/m³
9-22	Saprolite	Cohesion (τ) = 27.694 Kn/m³	Cohesion (c) = 21.447 Kn/m³	Cohesion (c) = 29.256 Kn/m³
		sliding angle(φ) = 24.570°	sliding angle(φ) = 19.956°	sliding angle(φ) = 22.896°
		Soil Fill Weight= 13.443 Kn/m³	Soil Fill Weight= 12.767 Kn/m³	Soil Fill Weight= 13.312 Kn/m³

- **Plaxis Input**

The inputs needed by Plaxis in the analysis of slope stability with the Mohr-Coloumb shear strength model are:

Table-9. The material used in Plaxis modeling on the south-southeast slopes.

Parameters	Name	Layers			Units
		Top Soil	Limonit	Saprolit	
Type of behavior	Type	Undrained	Undrained	Undrained	-
Soil unit weight above the phreatic level	γ_{unsat}	12,115	10,128	11,872	kN/m³
Soil unit weight below the phreatic level	γ_{sat}	18,440	16,720	15,013	kN/m³
Permeability in hor. Direction	K_x	0,000	0,000	0,000	m/day
Permeability in ver. Direction	Y_x	0,000	0,00	0,000	m/day
Young"s modulus (constant)	E_{ref}	5000	30000	50000	kN/m²
Poisson ratio	υ (nu)	0.300	0.150	0.150	-
Cohesion (constant)	c_{ref}	20.839	25.850	27.694	kN/m²
Friction angle	φ	24.570	21.306	24.570	°

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Table-10. The material used in Plaxis modeling on slope 2.

Parameters	Name	Layers			Units
		Top Soil	Limonit	Saprolit	
Type of behavior	Type	Undrained	Undrained	Undrained	-
Soil unit weight above the phreatic level	γ_{unsat}	11.163	12.357	10.171	kN/m^3
Soil unit weight below the phreatic level	γ_{sat}	13.734	18.201	15.363	kN/m^3
Permeability in hor. Direction	K_x	0.000	0.000	0.000	m/day
Permeability in ver. Direction	Y_x	0.000	0.000	0.000	m/day
Young‟s modulus (constant)	E_{ref}	5000	30000	50000	kN/m^2
Poisson ratio	υ (nu)	0.300	0.150	0.150	-
Cohesion (constant)	c_{ref}	25.056	12.925	21.447	kN/m^2
Friction angle	φ	21.390	22.626	19.956	^{o}

Table-11. The material used in Plaxis modeling on slope 3.

Parameters	Name	Layers			Units
		Top Soil	Limonit	Saprolit	
Type of behavior	Type	Undrained	Undrained	Type of behavior	Type
Soil unit weight above the phreatic level	γ_{unsat}	9.903	11.128	12.2014	kN/m^3
Soil unit weight below the phreatic level	γ_{sat}	13.734	14.494	14.4225	kN/m^3
Permeability in hor. Direction	K_x	0.000	0.000	0.0000	m/day
Permeability in ver. Direction	Y_x	0.000	0.000	0.0000	m/day
Young‟s modulus (constant)	E_{ref}	5000	30000	50000	kN/m^2
Poisson ratio	υ (nu)	0.300	0.150	0.1500	-
Cohesion (constant)	c_{ref}	16.436	27.665	29.2562	kN/m^2
Friction angle	φ	18.583	21.882	22.896	^{o}

B. Slope Geometry

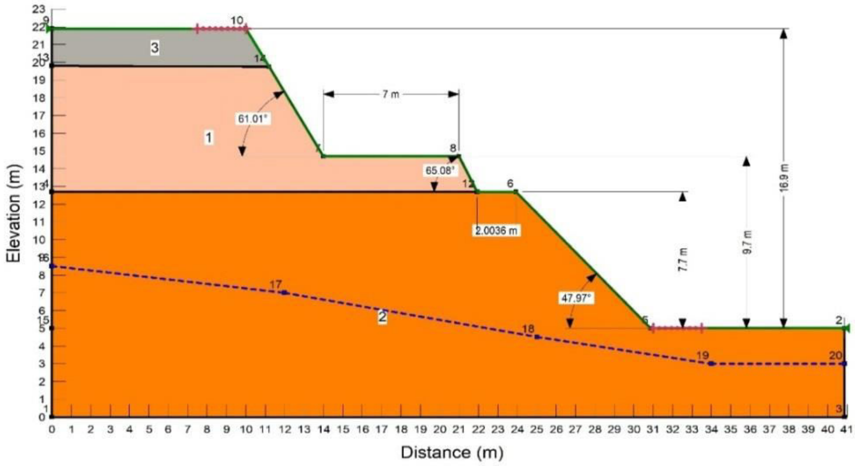

Figure-3. Slope Geometry 1.
(Coordinate: 121°19'10.215"E 1°53'56.07"S)

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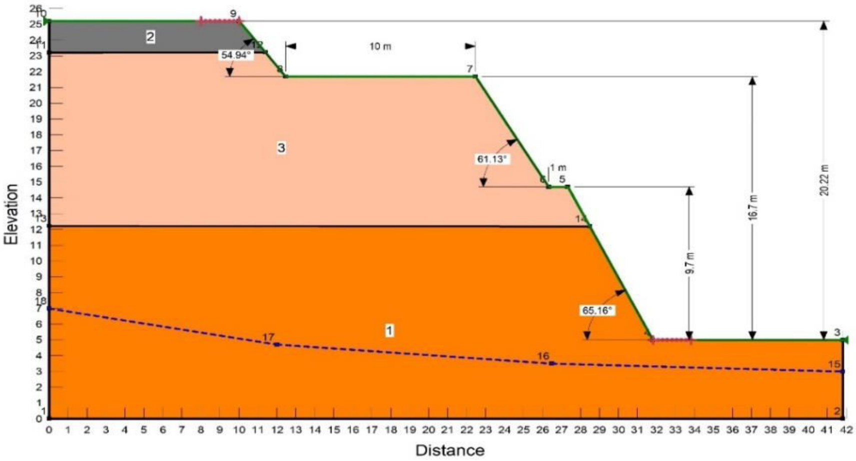

Figure-4. Slope Geometry 2.
(Coordinate: 121°19'18.176"E 1°53'40.089"S)

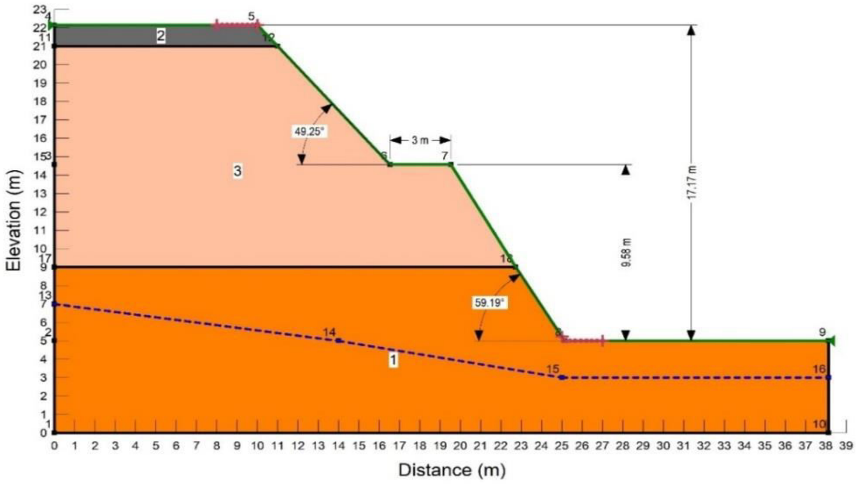

Figure-5. Slope Geometry 3.
(Coordinate: 121°19'9.097"E 1°53'38.024"S)

In this study, researchers examined 3 (three) sample slopes in Block B7 PT. Trinusa Dharma Utama, Lambolo Hamlet, Ganda-Ganda Village, Petasia District, North Morowali Regency, which is a slope formed based on the pit limit design in the Block area with considerations of safety and the value of its resource reserves.

Slopes are analyzed on slope conditions without and with the influence of loads on the slopes. The standard value of slope stability in this study is based on studies conducted and comprehensive studies on slope failure, divided into three groups of the Safety Factor (SF) range in terms of the intensity of the slide (Bowles, 1989), as shown in the following table.

Table-12. Relationship between slope safety factor and landslide intensity.

SF Value	Landslide Occurrence/Intensity
< 1.07	Landslides are common/frequent (unstable slopes)
1,07 < SF < 1,25	Landslide has occurred (critical slope)
> 1,25	Landslides are rare (slopes are relatively stable)

Source: Bowles (1989) in Hardiyatmo (2014)

Slope stability analysis was carried out using Slope/W software using the Bishop method. Where to find out how much the value of the safety number is on the original condition of the slope with the input soil data properties that have been previously proposed by researchers. The results of the analysis are slope stability with the Bishop method using Slope/W.

After analyzing slope stability using the Bishop method as the researchers have systematically described above, the value of slope stability on each slope in several conditions is summarized in the following table.

Table-13. Slope stability values on each slope in several conditions.

Slope	No Load	Machine Load	With Additional Earthquake Loads
1	1.985	1.923	1.026
2	0.948	0.929	0.483
3	1.523	1.503	0.882

A. Slope stability analysis without load

The analysis shows that slope 1 in the original condition without load such as the value of the total volume that dislodged was 121.24 m3, the total weight was 1,640 kN, the total inhibiting force was 33,527 kN/m and the total pushing force was 16,887 kN/m. The comparison between the total inhibiting force and the total pushing force is what produces the SF value of the slope of 1.985; the slope safety factor in the original no-load condition on slope 1 is above 1.25, which means the slope is relatively stable.

Slope 2 in the original condition without load such as the value of the total volume that dislodged was 139.35 m3, the total weight was 2,026.5 kN, the total inhibiting force was 41,029 kN/m and the total pushing force was 43,282 kN/m. The comparison between the total inhibiting force and the total pushing force produces an SF value of the slope of 0.948. The SF value on the slope is in an unstable condition, where landslides can often occur.

Slope 3 in its original no-load condition, such as the total volume that is displaced is 108.82 m3, the total weight is 1,402.9 kN, the total inhibiting force is 21,461 kN/m and the total pushing force is 14,091 kN/m. The comparison between the total inhibiting force and the total pushing force produces an SF value of the slope of 1.523. The SF value on the slope is in a stable condition.

B. Analysis of slope stability with heavy equipment loads working on the slope

The analysis shows that the heavy equipment load on the slope produces several parameters, including the value of the total volume which is 112.73 m3, the total weight is 1,523.7 kN, the total force that is inhibiting is 32,664 kN/m and the total force that pushes of 16,985 kN/m. The ratio between the total inhibiting force and the total pushing force is the SF value of the slope of the study area of 1.923. So that the safety factor of the slope in the original conditions with heavy equipment loads on the slope becomes critical, where landslides will occur at any time.

Slope 2 in the original condition with the load on the slope shows that the total volume displaced remains the same, namely 139.35 m3, the total weight remains at 2,026.5 kN, the total force that inhibits slightly increases to 41,807 kN/m and so does the total the pushing force increased to 45,011 kN/m. From the comparison between the total inhibiting force and the total pushing force, the SF value is smaller than before, with an SF value of 0.929. So this value shows the stability of slope 2 with the heavy equipment load on it is in an unstable condition, so landslides will often occur at that location.

Slope 3 in the original condition with the load on the slope showed that the total sliding volume increased slightly to 108.85 m3, the total weight also increased slightly from before to 1,403.3 kN, the total resisting force also increased slightly to 21,645 kN/m and likewise the total pushing force increased to 14,398 kN/m. From the comparison between the total inhibiting force and the total pushing force, the SF value is slightly smaller than before, with an SF value of 1.503. So this value shows the stability of slope 3 with the heavy equipment load on it is in a stable condition.

C. Slope stability analysis with additional earthquake loads

The results of the analysis show that the stability of slope 1 in the original conditions with the addition of earthquake loads resulted in a total value of the inhibiting force decreased to 28,593 kN/m and the total pushing force increased drastically to 27,875 kN/m, so from the comparison between the total inhibiting force and the total acting force pushing, resulting in an SF value of the slope of 1.026. The slope safety factor in the original conditions with the additional earthquake load on the slope causes a drastic decrease in slope stability, which from the SF value obtained indicates unstable slope conditions so that landslides on these slopes will often occur.

The results of the analysis on slope 2 show that the total inhibiting force has increased to 60,211 kN/m and so has the total pushing force increased to 1,2462x1005 kN/m. So thus the addition of the landslide load results in a smaller SF value than before, which is equal to 0.483. This value shows that the stability of slope 2 with additional landslide loads is in an unstable condition, so if an earthquake occurs simultaneously with the activity of heavy equipment loads on it, landslides will certainly occur on that slope.

The results of the analysis on slope 3 show that the total inhibiting force has decreased to 21,014 kN/m while the total pushing force has increased to 23,815 kN/m. Thus, the addition of the landslide load resulted in a significantly decreased SF value from the previous one, which was 0.882. This value shows that the stability of slope 3 with additional landslide loads is in an unstable condition, so if an earthquake occurs simultaneously with the activity of heavy equipment loads on it, it can be ascertained that landslides will occur on that slope.

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4.3 Slope Deformation in Open Pit Mining Area in Morowali Regency

Furthermore, the results of slope deformation analysis based on the slope displacement values in various conditions using Plaxis 2D can be seen in the following table.

Table-14. Value of slope deformation on each slope in several conditions.

Slope	No Load (m)	Machine Load (m)	With Additional Earthquake Loads (m)
1	$9.45x10^{-3}$	$36.97x10^{-3}$	$37.43x10^{-3}$
2	$17.86x10^{-3}$	$19.11x10^{-3}$	$19.30x10^{-3}$
3	11.56×10^{-3}	$26.68x10^{-3}$	$26.69x10^{-3}$

After analysis with Plaxis, it was found that the condition of slope 1 without a load on it produces a total displacement value of 9.45x10-3 m, which indicates a deformation of 0.945 cm, the condition of slope 2 without a load on it produces a total displacement value of 17. 86x10-3 m, which shows a deformation of 1.786 cm, the condition of slope 3 without a load on it produces a total displacement value of 11.56 x 10-3 m, which indicates a deformation of 1.156 cm.

After analysis with Plaxis, it was found that on slope 1 after being loaded with heavy equipment on it, it significantly increased the total displacement value on the slope; this is evidenced by the results of the analysis which showed a total displacement value of 36.97x10-3 m, which shows a deformation of 3.697 cm. While the condition of slope 2 after being given a load, there is a significant increase in the deformation value to 19.11x10-3 m, which indicates a deformation of 1.911 cm. As for the condition of slope 3 after being loaded there was a significant increase in the deformation value to 26.68x10-3 m, which indicated a deformation of 2.668 cm.

Furthermore, an analysis with Plaxis showed that on slope 1 after being given an additional heavy equipment load and an earthquake, it significantly increased the total displacement value on the slope, this is evidenced by the results of the analysis which showed a total displacement value of 37.43x10-3 m, which shows a deformation of 3.743 cm. Meanwhile, for the condition of slope 2 after being given an additional earthquake load there was a significant increase in the deformation value to 19.30x10-3m, which indicated a deformation of 1.930 cm. Then the condition of slope 3 after being given an additional earthquake load there was a significant increase in the deformation value to 26.69x10-3m, which indicated a deformation of 2.669 cm.

4.4 Design of Safe Slope Geometry

A. Slope 1

To obtain a safe stability value, the researcher tried to modify the geometry of the slope by changing the size of the second bench from the previous one which had a width of 7 m to 3.1 m, and the height of the bench was also changed from previously having a height of 9.7 m to 7.7 m. The third or last bench was widened from the previous 2 m to 8.3 m, while the bench height was also changed from the previous 7.7 m to 4.1 m. Changing the dimensions of each bench also changed the slope angle on the top slope from 61.01^o to 74.78^o. For the second or middle slope, there is also a change, from the previous slope angle of 65.08^o to 71.76^o. Meanwhile, for the third or lowest slope, it has also changed, from the previous slope angle of 47.97^o, it was changed to 53.97^o. As for the results of the analysis of slope stability after repairs to the geometry of the slope, the following results are obtained.

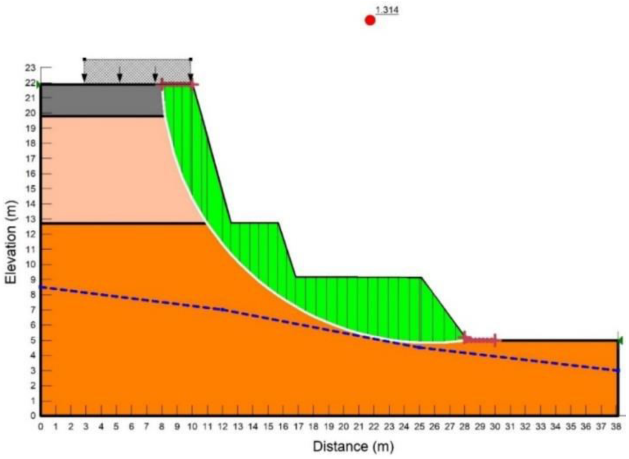

Figure-6. Slope 1 stability analysis with all loads after correcting the geometry.

The results of the analysis show that after improving the geometry of slope 1 it produces better stability even though it has been loaded with heavy equipment and earthquakes, where the SF value obtained is greater than before, namely 1.314. This is due to the large total value of the inhibiting force (19,258 kN/m) compared to the total pushing force (14,658 kN/m).

B. Slope 2

In addition to the south-southeast slopes, to obtain a safe stability value on slope 2, the researcher also modified the geometry on the slope by changing the size of the second bench from the previous one which had a width of 10 m to 4 m, and the height of the bench was also changed from previously having a height 16.7m to 8.2m. The third or last bench was widened from the previous one measuring 1 m to 11.1 m, while the height of the bench was also changed from previously having a height of 9.7 m to 2.9 m. Changing the dimensions of each bench also changed the slope angle on the top slope which was previously 54.94^{o} to 78.33^{o}. For the second or middle slope, there is also a change, from the previous slope angle of 61.13o to 72.4^{o}. Meanwhile, for the third or lowest slope, it has also changed, from the previous slope angle of 65.16^{o}, it was changed to 38.29^{o}. As for the results of the analysis of slope stability after repairs to the geometry of the slope, the following results are obtained.

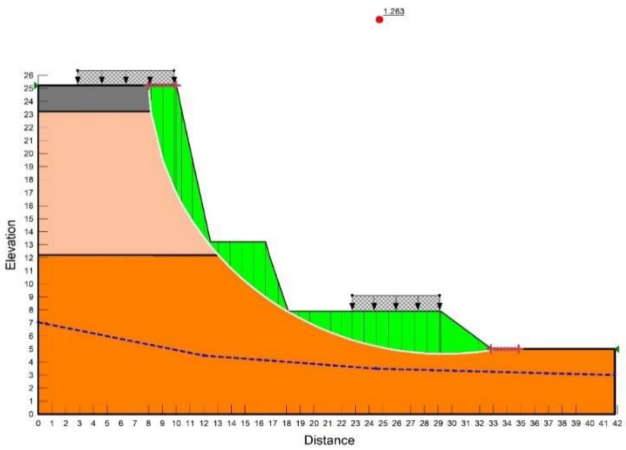

Figure-7. Slope stability analysis 2 with all loads after correcting the geometry.

The results of the analysis show that after improving the geometry of the slope of the Block B7 mine section, it produces better stability even though it has been loaded with heavy equipment and earthquakes, where the SF value obtained is greater than before, namely 1.263. This is due to the large total value of the inhibiting force (20,576 kN/m) compared to the total pushing force (16,289 kN/m).

C. Slope 3

In addition to slope 1 and slope 2, to obtain a safe stability value on slope 3, the researcher also modified the geometry on the slope by increasing the number of benches from previously there were only 2 benches modified to 3 benches, the second bench on the slope has a width of 4.185 m, located at a height of 8.58 m from the bottom of the slope. The third bench on the slope has a width of 9.688 m and is at a height of 4 m from the bottom of the slope. From this slope improvement, the slope angle value on the top slope reached 73.47^{o}. For the second or middle slope, a slope angle of 65.66^{o} is obtained. Meanwhile, the third or lowest slope has a slope angle of 67.52^{o}. As for the results of the analysis of slope stability after repairs to the geometry of the slope, the following results are obtained.

The results of the analysis show that after improving the slope geometry of the Block B7 mine section, it produces better stability even though it has been loaded with heavy equipment and earthquakes, where the SF value obtained is greater than before, namely 1.330. This is due to the large total value of the inhibiting force (23,805 kN/m) compared to the total pushing force (17,893 kN/m).

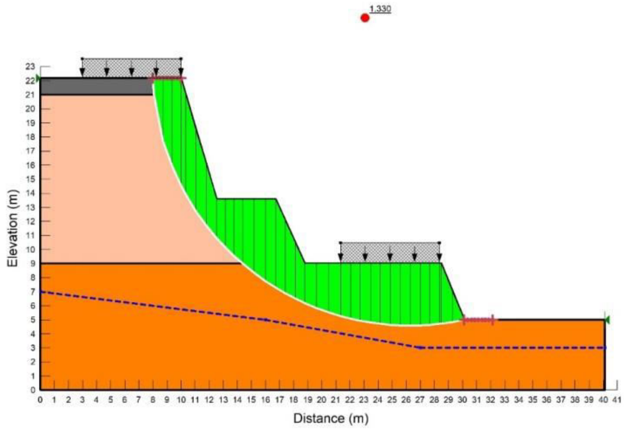

Figure-8. Slope stability analysis 3 with all loads after correcting the geometry.

5. CONCLUSIONS AND SUGGESTIONS

5.1 Conclusion

Based on the results of the research discussed in the previous chapter, it can be concluded that:

a) Nickel ore is located in the North Morowali area, to be precise, in the IUP of PT. Trinusa Dharma Utama in Ganda-Ganda Village, Petasia District, belongs to the nickel laterite and silicate (garnierite) types. Laterite deposits start from weathering ultramafic rocks (peridotite, dunite, serpentinite) which contain lots of olivines, pyroxene, magnesium silicate, and iron silicate minerals. The lateralization process in lateritic nickel deposits is defined as a leaching process of soluble minerals and silica minerals from the laterite profile in an acidic, warm, and humid environment, and forms a concentration of precipitate resulting from the enrichment of the lateralization process in the elements Fe, Cr, Al, Ni, and Co. The content of the elements Fe and Al2O3 is high in the limonite zone, the minerals contained are dominated by oxide minerals namely manganese, hematite, goethite, and a little silica is also found, this is due to the oxidation process of the elements Fe and Al2O3 besides that these elements also have non-mobile properties. From the surface, the lower the depth, the lower the value of Fe and Al2O3 while the Ni, SiO2, and MgO increase. In the saprolite layer, the tendency for Ni is greater. Then the distribution of nickel laterite zones in the study area, especially in the limonite and saprolite zones, shows that the distribution has a north-south orientation on the western ridge and a west-east orientation to the southeast in the central to eastern parts of the study area. In this area, it is also seen that the enrichment process of the Ni element occurs optimally so that it can produce relatively high levels when compared to other morphologies.

b) Regarding the results of the analysis of the value of the slope safety factor in this study, the results are as follows:

a. For slope stability value 1 under no-load conditions, it produces a stable slope situation, because the resulting SF value is 1.985. When loaded with heavy equipment, the condition of the slope turned critical with an SF value of 1.923. Until then the condition turned unstable when the earthquake load was added to the slope, with an SF value of 1.026.

b. For slope stability value 2 when no load produces an SF value of 0.948. With heavy equipment loads, the SF value obtained decreases to 0.929. Then when the earthquake load is added, the resulting SF value gets smaller, which is equal to 0.483. The stability value obtained indicates that the slope is in an unstable condition.

c. For slope stability values of 3 when no load produces an SF value of 1.523. With heavy equipment load, the obtained SF value decreased to 1.503. Then when the earthquake load is added, the resulting SF value gets smaller, which is equal to 0.882. From the stability value obtained, it shows that after being given an earthquake load, the condition of the slope changes to become unstable after previously being in a stable state when without a load and under the weight of heavy equipment.

c) Regarding the deformation that occurs on the slopes at the research location, it shows that the condition of slope 1 without load produces a total displacement value of 9.45x10-3m, and after being loaded with heavy equipment significantly increases the deformation value, this is evidenced by the results of the analysis which shows the total value displacement of 36.97x10-3m and increased again after adding earthquake loads with a total displacement value of 37.43x10-3m. Furthermore, the condition of slope 2 without load produces a total displacement value of 17.86x10-3m, and after being loaded there is an increase in the deformation value to 19.11x10-3 m, then there is a slight increase after adding earthquake loads with a total displacement value of 19.30x10-3m. The condition of slope 3 without load produces a total displacement value of 11.56 x 10-3m, after being loaded there is an increase in the deformation value to 26.68x10-3 m, then there is a slight increase after adding earthquake loads with a total displacement value of 26.69x10 -3m.

d) To produce safe slope stability, it is necessary to make changes to the geometric design of the two slopes to produce stable slopes.

a. On slope 1, it is necessary to improve the geometry by changing the size of the second bench to 3.1 m, and also changing the height of the bench to 7.7 m. The third or last bench was widened to 8.3 m, while the bench height was also changed to 4.1 m. Changing the dimensions of each bench also changes the slope angle on the top slope to 74.78^{o}. For the second or middle slope, it becomes 71.76^{o}. Meanwhile, for the third or lowest slope, it is also changed to 53.97^{o}.

b. On slope 2, changes need to be made by changing the size of the second bench to 4 m, and the height of the bench is also changed to 8.2 m. The third or last bench was widened to 11.1 m, while the bench height was also changed to 2.9 m. The change in each bench also changed the slope angle on the top slope to 78.33^{o}. For the second or middle slope, it also changes to 72.4^{o}. Meanwhile, the third or lowest slope also experienced a change to 38.29^{o}.

c. For slope 3, changes were made by increasing the number of benches from previously there were only 2 benches modified to 3 benches, the second bench on the slope has a width of 4.185 m, located at a height of 8.58 m from the bottom of the slope. The third bench on the slope has a width of 9.688 m and is at a height of 4 m from the bottom of the slope. From this slope improvement, it was obtained that the slope angle value on the top slope reached 73.47^{o}. For the second or middle slope, a slope angle of 65.66^{o} is obtained. Meanwhile, the third or lowest slope has a slope angle of 67.52^{o}.

5.2 Suggestions

a) In mining operations, every company must carry out mining activities by referring to the principles of good mining practices. This is because the correct mining procedures will greatly affect mining business activities. After all, mining business activities will be more economical, efficient, and the safety of workers and environmental sustainability will be more guaranteed.

b) The collection of low-grade nickel must be conducted under the FS and also the RKAB. Post-mining reclamation must be processed by following the applicable regulations.

REFERENCES

Cosner Kevin. 2019. Analisis Stabilitas Lereng Dengan Perkuatan Geogrid Sebagai Tulangan Menggunakan Metode Elemen Hingga Dan Metode Bishop (Studi Kasus: Panyabungan GI 150 kv). Tugas Akhir Departemen Teknik Sipil, Fakultas Teknik, Universitas Sumatera Utara.

Das Braja M. 1995. Mekanika Tanah dan Prinsip Rekayasa Geoteknis. Jakarta: Penerbit Erlangga.

Gazali Akhmad, Abdurahim Sidiq, dan Adhi Surya. 2020. Analisis Stabilitas Lereng Dan Penanggulangan Longsoran Menggunakan Program Plaxis V. 8.2. Jurnal Kacapuri, Volume 3, Nomor 1, Hlm. 1-13.

Hardiyatmo H.C. 2014. Mekanika Tanah 2, 5th Ed. Yogyakarta: Gadjah Mada University Press.

Rajagukguk dan Monintja. 2014. Analisis Kestabilan Lereng Dengan Metode Bishop (Studi Kasus: Kawasan Citraland sta.1000m). Jurnal Sipil Statik, Volume 2 Nomor 3, Hlm. 139-147.